Ambient Noise Measurements and Inversions in Coastal and Continental Shelf Waters

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LONG-TERM GOALS

The long term objectives are to: (1) study the role of wave-induced bubble plumes in ambient noise generation, and (2) characterize acoustic scattering from high void fraction bubble plumes at the sea surface. The origin of the numbers and sizes of bubbles produced within whitecaps, the $f^{-5/3}$ dependence of wave-induced noise power on frequency, and the relationship between noise level and surface wave energy dissipation are of particular interest.

OBJECTIVES

There are two short-term objectives. The first is to characterize the internal structure of wave induced bubble plumes in the open ocean on length scales of order 10 cm and sub-second time scales while simultaneously measuring the environmental parameters driving plume creation, the scattering of sound from the plume between 5-50 kHz and the ambient noise generated during plume formation. The measurement of plume scale, roughness, and bubble sizes are particularly important. The second set of short-term objectives were to quantify the numbers and sizes of bubbles produced by breaking waves during the air entrainment phase of wave breaking, and understand the fluid mechanical origin of the bubble size distribution. Understanding the origin of the bubble spectrum is key to understanding ambient noise generation in the open ocean, and acoustical scattering at the ocean surface.

APPROACH

The underlying approach is based on breaking wave experiments in the laboratory and open-ocean. The purpose of the laboratory studies was to image the short time-scale, short length-scale fluid dynamical processes underlying bubble creation inside breaking waves. In addition to yielding insight into the processes associated with bubble formation, high-speed video measurements provided estimates of the bubble size distributions present during the actual process of wave breaking. The noise generated by the laboratory breakers was measured simultaneously with the video images to study the link between noise generation and bubble production. This approach has proven effective, and the results are discussed below.

The open-ocean ocean studies, scheduled for 2002, are based on an instrumentation package (Advanced Plume Imaging Experiment, or APEX) funded by an ONR DURIP and currently under construction. APEX is a multi-sensor package designed to probe the structure of dense bubble plumes

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14. ABSTRACT
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beneath ocean whitecaps on several simultaneous spatial scales. It includes an optical bubble counter, an array of ring conductivity sensors, a conductivity/temperature sensor, an acoustic Doppler velocity profiler, an acoustic system for measuring plume scattering cross-section, and an underwater video camera. These sensors will simultaneously measure the bubble size distribution and void fraction of air within whitecap plumes, the size of the plumes and scaling of plume size with sea state, the acoustical roughness scales of the plume boundaries and the noise radiated during plume formation. Two acoustic wave meters will provide estimates of wave energy dissipated during breaking.

WORK COMPLETED

The laboratory studies to investigate air entrainment mechanisms are complete. A series of experiments were conducted in a SIO seawater flume (33 m long, 0.5 m wide, 0.6 m deep). Wave packets were generated at one end of the flume using a computer controlled wave paddle that produced plunging breakers approximately 10 cm in height. Over 600 breaking events were imaged through the glass-walled side of the flume using a high-speed video camera. The data from these experiments has been analyzed and is described below.

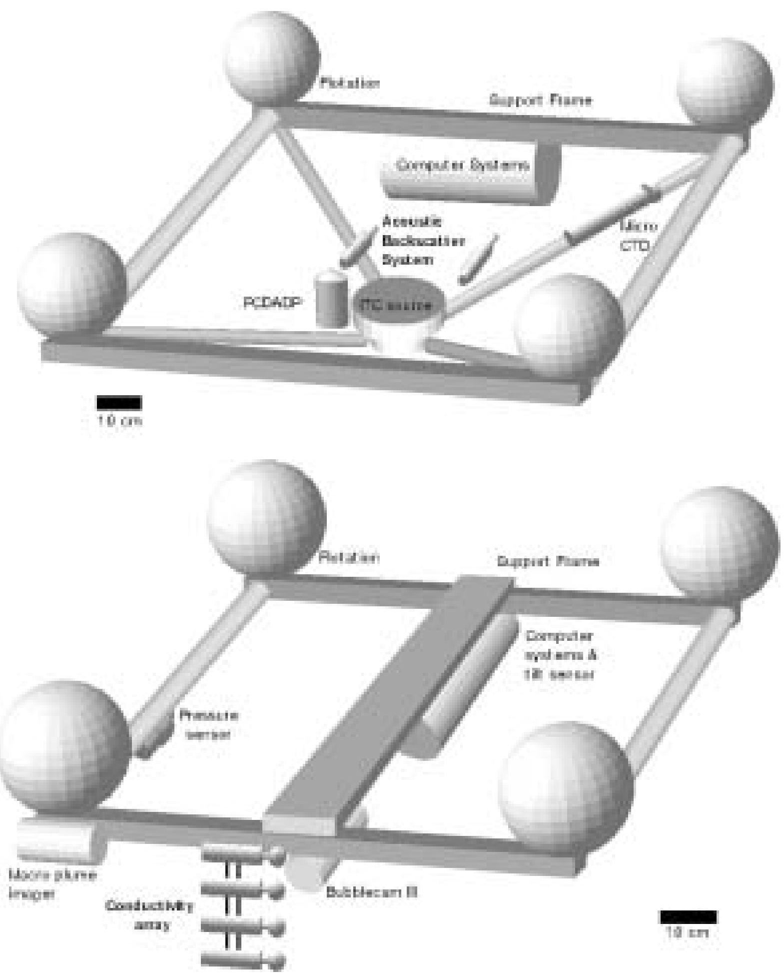

Figure 1. A drawing of the two instrumentation packages that make up the APEX system. The top frame supports the acoustic backscatter system and the bottom frame supports the optical and conductivity sensors.

The instrumentation package for the open-ocean experiments is still under construction. Figure 1 shows the sensor configuration for the optical and acoustical systems. Most of the major sensor packages and PC104-based data acquisition systems have been purchased. Sensor data integration and software development is progressing, and the first engineering trials are scheduled for early 2002.

RESULTS

There are two significant results from the breaking wave flume studies. The first of these is that, although different bubble formation mechanisms act at different times and regions throughout a breaking wave event, there is an underlying fragmentation processes that controls the bubble spectrum. This result is summarized in Figure 2.

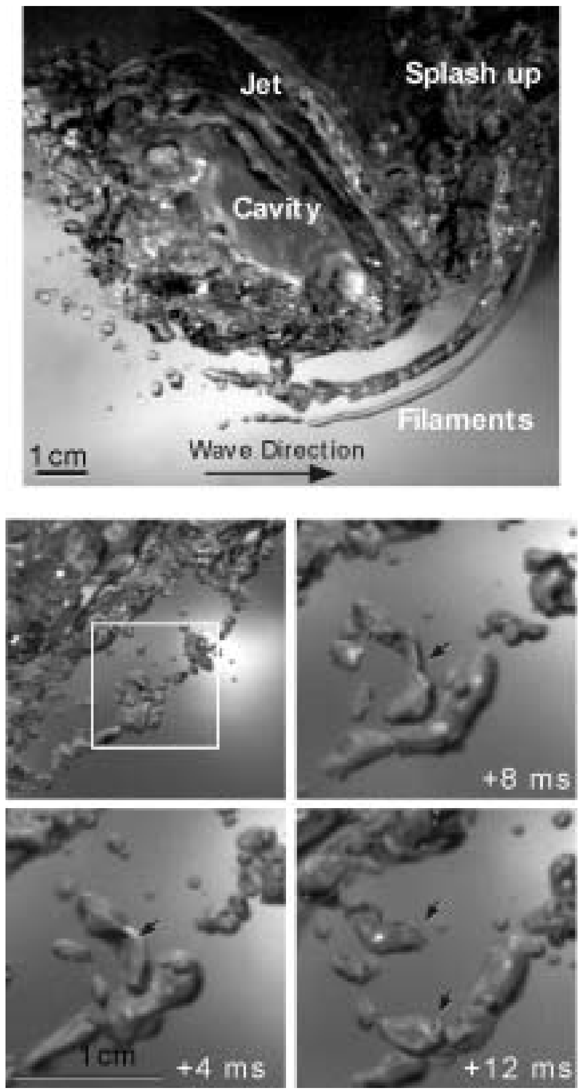

Figure 2. The top plate shows a cross-sectional view of the air entrainment regions occurring inside a breaking wave crest. The feature labeled 'jet' shows the overturning wave crest impacting the leading edge of the wave. The lower four frames show the bubble remnants from an air filament fragmenting in turbulent flow.

Bubbles are created within the splash-up, cavity and air filament regions, each of which tends to produce bubbles with characteristic sizes. Once formed, however, bubbles are subjected to turbulent fragmentation. Secondary turbulent fragmentation operates continuously throughout the breaking event and thus masks any fluid dynamical signature left in the bubble spectrum by coherent flow features such as splash-up and air filaments.

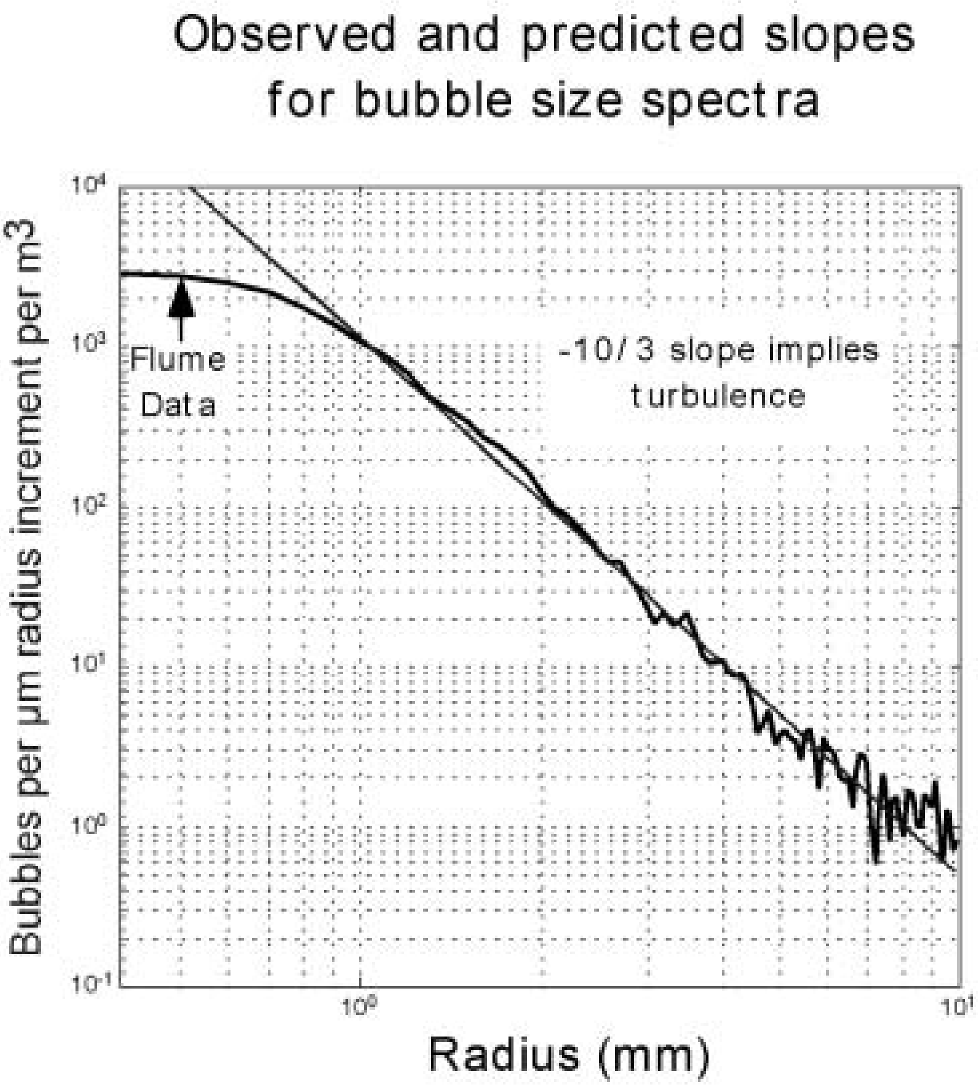

Figure 3. The bubble size spectrum inside a laboratory breaking wave estimated from high-speed video images. The vertical scale is number of bubbles per cubic meter in a 1-micrometer radius bin. The size spectrum scales almost exactly as (radius)$^{-10/3}$. The roll-off in the distribution for bubbles less than 1 mm in radius is due to the limited optical resolution of the imaging system used.

The second result is that the bubble spectrum follows a simple scaling law determined by turbulent fragmentation. The bubble size spectrum shown in Fig. 3 was estimated from approximately 225 video images taken during the bubble-formation phase of 9 breaking events. Between the largest bubbles observed and the optical limit of the camera (1 mm to 10 mm), the bubble size distribution scales as (radius)$^{-3.2}$, where the slope has a correlation coefficient of –0.99. This slope varies between –3.2 and –3.4 depending on the exact range of bubble radii chosen for the linear regression analysis and bounds the –10/3 slope predicted by Garret, Ming and Farmer (2000) for bubble breakup dominated by turbulent fragmentation. Thus the weight of the experimental evidence is that the origin of the bubble size distribution created by breaking waves is dominated by turbulent bubble breakup and follows a simple (radius)$^{-10/3}$ scaling law.

IMPACT/APPLICATIONS

Wave-induced bubble plumes play a central role in ambient noise generation, high frequency acoustic scattering at the sea surface, acoustic communications through the littoral zone and air-sea mixing. The particularly simple model arising from these laboratory studies could form the starting point for understanding these complex and inter-related phenomena.

TRANSITIONS

None.

RELATED PROJECTS

None.

REFERENCES

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PUBLICATIONS

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